Stream Segment Temperature Model (SSTEMP) Version 1.0.0
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by

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INTRODUCTION

SSTEMP is a much-scaled down version of the Stream Network Temperature Model (SNTEMP) written by Theurer et al. (1984). SSTEMP may be used to evaluate alternative reservoir release proposals, analyze the effects of changing riparian shade or the physical features of a stream, and examine the effects of different stream withdrawals and returns on instream temperature. Unlike the large network model, SNTEMP, this program handles only single stream segments for a single time period (e.g., month, week, day) for any given "run". However, the program may be used satisfactorily for a variety of simple cases that one might face on a day-to-day basis. It is especially useful as both a teaching tool and a sensitivity analysis tool.

The program requires inputs describing the average stream geometry, as well as (steady-state) hydrology and meteorology, and stream shading.   SSTEMP optionally estimates the combined topographic and vegetative shade as well as solar radiation penetrating the water. It then predicts the mean daily water temperatures at some specified distance(s) downstream. It also estimates the daily maximum and minimum temperatures. The program also handles the special case of a dam with steady-state release at the upstream end of the segment, unlike SNTEMP.

With good quality input data, SSTEMP should faithfully reproduce mean daily water temperatures throughout a stream reach. If it does not, there is a research opportunity to explain why not. One should not expect too much from SSTEMP if the input data are poor or if the modeler has not adhered to the model's assumptions.

Suggested citation:
Bartholow, J.M. 1999. SSTEMP for Windows: The Stream Segment Temperature Model (Version 1.1.3).
    US Geological Survey computer model and help file.
        http://www.mesc.usgs.gov/rsm/rsm_download.html#TEMP

RUNNING SSTEMP

SSTEMP has been designed for a monitor with at least 1024 x 768 resolution using the Windows small fonts. If your monitor does not meet these standards, you will get a message to this effect and SSTEMP's main screen image will be reset to a smaller size. This may be toggled by **View|Large Form**.

You will be presented with a screen showing the multitude of possible program inputs, organized into logical groups. The program starts with a set of "default" values to show the approximate magnitude of the numbers and should not be used without thought or review. At the bottom of the screen, you may double click to enter a descriptive title, handy for output, if you are using the large screen view.

As the program runs, it calculates several intermediate values that may be useful in calibration. These are printed on the top right portion of the screen. It also prints the mean heat flux values for the segment immediately below on the screen. Outflow temperatures (mean, maximum, and minimum) that result from this set of input parameters are displayed on the bottom right side of the screen, as are the daily equilibrium temperatures.

You may change any parameter by using your mouse to highlight the desired parameter and then typing the new value for that parameter. Each new value must be terminated by an ENTER or a tab key, or a new mouse click. The menu and toolbar will be disabled until your entry is complete. Entering a new value for any parameter will immediately update the predicted temperatures.

You may choose the units of display (English or International) for each input and output item. This choice may be "global" by using the **VIEW** menu or the toolbar buttons, or singly by double clicking on the appropriate label describing the parameter. Units are red if English and blue if International. **Note** that not all input or output values have units that differ between systems. These will remain black.

Files may be **SAVE**d to a text file and subsequently **OPEN**ed for reuse. You will be prompted for saving your file upon **EXIT**ing. Nothing fancy here.

Toolbar Buttons (Only visible with the **large form** view)

 View all English units button

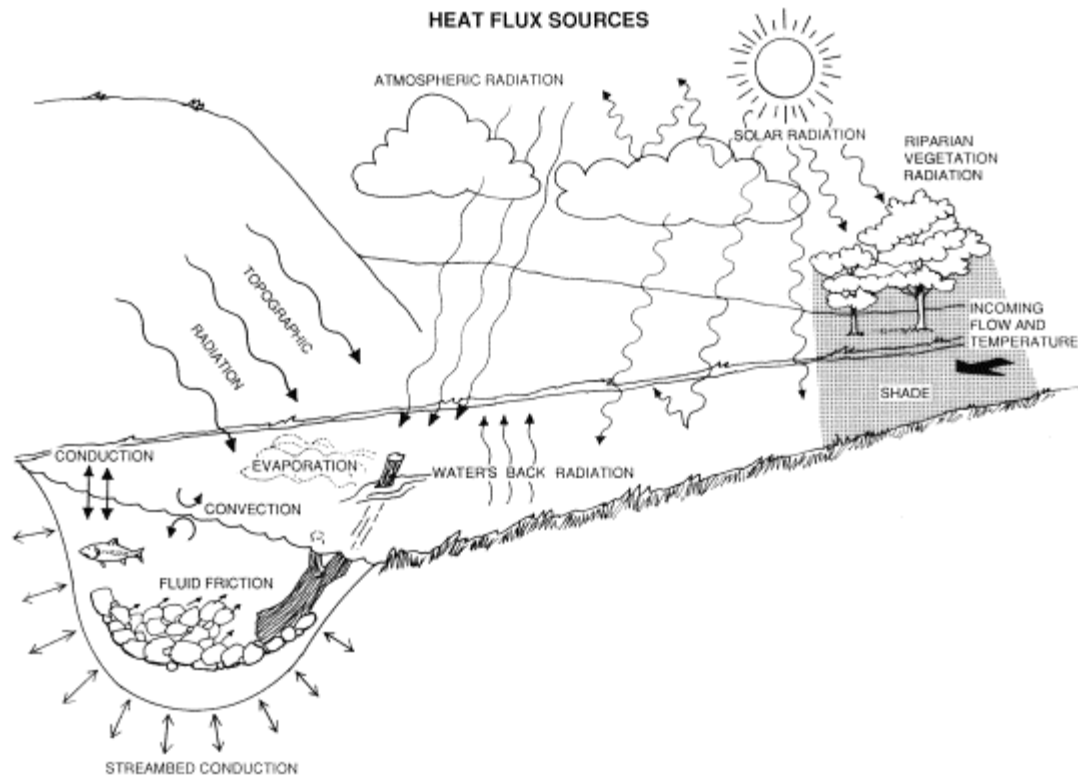 View all International units button

 Swap all units button

 View sensitivity analysis

 View Flow/Distance matrix

DESCRIPTION OF LOGIC

In general terms, SSTEMP calculates the heat gained or lost from a parcel of water as it passes through a stream segment. This is accomplished by simulating the various heat flux processes that determine that temperature change (see figure below). These physical processes include convection, conduction, evaporation, as well as heat to or from the air (long wave radiation), direct solar radiation (short wave), and radiation back from the water. SSTEMP first calculates the solar radiation and how much is intercepted by (optional) shading. This is followed by calculations of the remaining heat flux components for the stream segment. The details are just that: To calculate solar radiation, SSTEMP computes the radiation at the outer edge of the earth's atmosphere. This radiation is passed through the attenuating effects of the atmosphere and finally reflects off the water's surface depending on the angle of the sun. For shading, SSTEMP computes the day length for the level plain case, i.e., as if there were no local topographic influence. Next the local topography is factored in by computing the sunrise and sunset times based on the east and west-side topography. Thus, the local topography results in a percentage decrease in the level plain daylight hours. From this local sunrise/sunset, the program computes the percentage of light that is filtered out from the riparian vegetation. This filtering is the result of the size, position and density of the shadow-casting vegetation on both sides of the stream.

HEAT FLUX SOURCES

ATMOSPHERIC RADIATION

SOLAR RADIATION

RIPARIAN
VEGETATION
RADIATION

TOPOGRAPHIC
RADIATION

INCOMING
FLOW AND
TEMPERATURE

SHADE

CONDUCTION

EVAPORATION

WATER'S BACK RADIATION

CONVECTION

FLUID FRICTION

STREAMBED CONDUCTION

Please refer to Theurer et al. (1984) for the source and derivation of the formulae and computing methodology contained in this program.

HYDROLOGY PARAMETERS

This section contains the mean daily values for hydrology. The default screen looks like:

Hydrology	
Segment Inflow (cfs)	50.000
Inflow Temperature (°F)	70.000
Segment Outflow (cfs)	51.000
Accretion Temp. (°F)	55.000

   1. Segment Inflow (cfs or cms) — Enter the mean daily flow at the top of the stream segment. If the segment begins at an effective headwater, the flow may be entered as zero; all accumulated flow will accrue from lateral inflow, both surface and groundwater. If the segment begins at a reservoir, the flow will be the outflow from that reservoir. Remember that this model assumes steady-state flow conditions.

If the inflow to the segment is the result of mixing two streams, you may use the mixing equation to compute the combined temperature:

$$T_j = \frac{Q_1 {*} T_1 + Q_2 {*} T_2}{Q_1 + Q_2}$$

where

T_j = temperature below the junction

Q_n = discharge of source n

T_n = temperature of source n

2. Inflow Temperature (°F or °C) — Enter the mean daily water temperature at the top of the segment. If the segment begins at a true headwater, you may enter any water temperature, because zero flow has zero heat. If there is a reservoir at the inflow, use the reservoir release temperature. Otherwise, use the outflow from the upstream segment.

3. Segment Outflow (cfs or cms) — The program calculates the lateral discharge by knowing the flow at the head and tail of the segment, subtracting to obtain the net difference, and dividing by segment length. The program assumes that lateral inflow (or outflow) is uniformly apportioned through the length of the segment. If any "major" tributaries enter the segment, you probably should divide the segment into two or more subsections. "Major" is defined as any stream contributing greater than 10% of the mainstem flow.

4. Accretion Temperature (°F or °C) — The temperature of the lateral inflow, barring tributaries, generally should be the same as groundwater temperature. In turn, groundwater temperature may be approximated by the mean annual air temperature. You can verify this by checking United States Geological Survey (USGS) well log temperatures. Exceptions may arise in areas of geothermal activity. If irrigation return flow makes up most of the lateral flow, it may be warmer than mean annual air temperature. Return flow may be approximated by equilibrium temperatures.
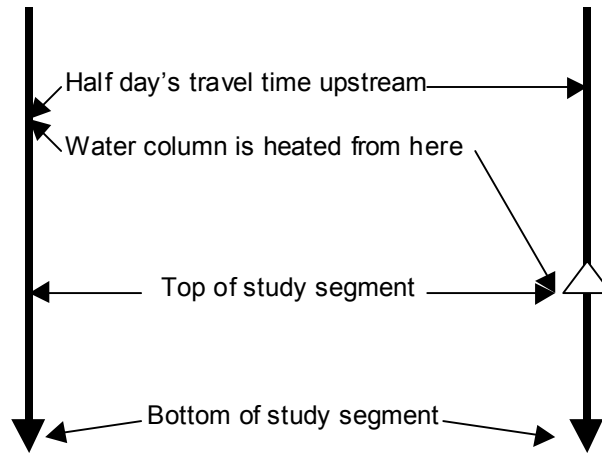
GEOMETRY PARAMETERS

The default screen for stream geometry components looks like:

Geometry	
Latitude (degrees)	40.000
Dam at Head of Segment	☐
Segment Length (mi)	10.000
Upstream Elevation (ft)	100.000
Downstream Elevation (ft)	0.000
Width's A Term (s/ft²)	12.500
B Term where W = A*Q**B	0.200
Manning's n	0.035

1. Latitude (decimal degrees or radians) — Latitude refers to the position of the stream segment on the earth's surface. It may be read off of any standard topographic map.

2. Dam at Head of Segment (checked or unchecked) — If there is a dam at the upstream end of the segment with a constant, or nearly constant diel release temperature, check the box, otherwise leave it

Case 1 - Without Dam   **Case 2 - With Dam**

Half day's travel time upstream

Water column is heated from here

Top of study segment

Bottom of study segment

unchecked. This option, unavailable in SNTEMP, is important for more accurately estimating daily maximum water temperatures. Maximum daily water temperature is calculated by following a water column from solar noon to the end of the segment, allowing it to heat up towards the maximum equilibrium temperature. If there is an upstream dam within a half-day's travel time from the end of the segment, a parcel of water should only be allowed to heat for a shorter time/distance. By telling SSTEMP that there is a dam at the top, it will know to heat the water only from the dam downstream. Figure 1 may help explain the situation.

Just to confuse the issue, be aware that if there is no dam SSTEMP will assume that the stream segment's meteorology and geometry also apply upstream to that point a half day's travel time from the end of the segment. If conditions are vastly different upstream, this is one reason that the maximum temperature estimate can be inaccurate.

Figure 1. Calculating maximum daily temperature with and without an intervening dam.

  3. Segment Length (miles or kilometers) — Enter the length of the segment for which you want to predict the outflowing temperature. Remember that all parameters will be assumed to remain constant for the entire segment. Length may be estimated from a topographic map, but a true measurement is best.

  4. Upstream Elevation (feet or meters) — Enter elevation as taken from a 7-1/2 minute quadrangle map.

  5. Downstream Elevation (feet or meters) — Enter elevation as taken from a 7-1/2 minute quadrangle map. Do not enter a downstream elevation that is higher than the upstream elevation, lest a "Catastrophic Error" occur.

  6. Width's A Term (seconds/foot^2 or seconds/meter^2) — This parameter may be derived by calculating the wetted width-discharge relationship. Again, an experienced hydrologist can help. To conceptualize this, plot the width of the segment on the Y-axis and discharge on the X-axis of log-log paper. Be sure to use consistent units. Three or more measurements are much better than two. The relationship should approximate a straight line, the slope of which is the B term (the next parameter). Theoretically, the A term is the Y intercept. However, the width vs. discharge relationship tends to break down at very low flows. Thus, it is best to calculate B as the slope and then solve for A in the equation:

$$W = A * Q^B$$
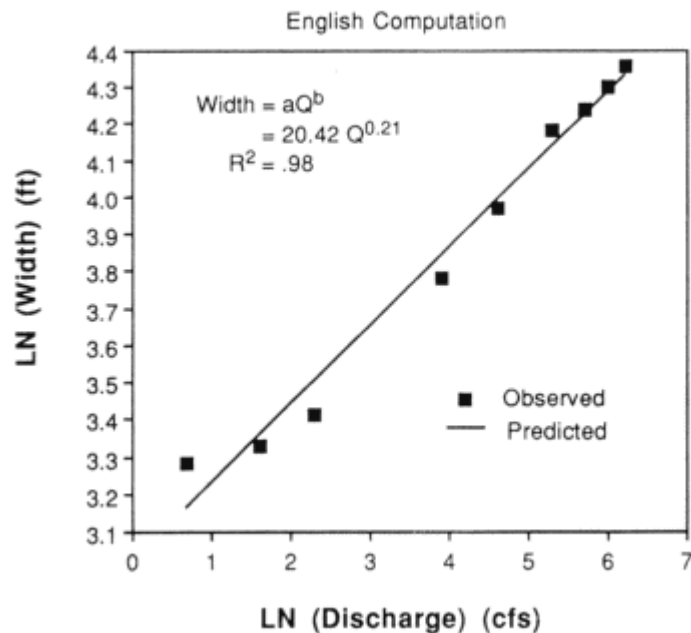
where   Q is a known discharge, and
            W is a known width
            B is the power relationship

Regression analysis also may be used to develop this relationship. First transform the flow to natural log (flow) and width to natural log (width). Log (width) will be the dependent variable. The resulting X coefficient will be the B term and the (non-zero) constant will be the A term when exponentiated. That is:

A = e^constant from regression, where ^ represents exponentiation

As you can see from the width equation, width equals A if B is zero. Thus, substitution of the stream's actual wetted width for the A term will result if the B term is equal to zero. This is satisfactory if you will not be varying the flow, and thus the stream width, very much in your simulations. If, however, you will be changing the flow by a factor of 10 or so, you should go to the trouble of calculating the A and B terms more precisely. Width can be a sensitive factor under many circumstances.

POUDRE RIVER WIDTH-FLOW RELATIONSHIP
English Computation

A graph with LN (Width) (ft) on the y-axis ranging from 3.1 to 4.4, and LN (Discharge) (cfs) on the x-axis ranging from 0 to 7. The equation shown is:

$$\text{Width} = aQ^b = 20.42\, Q^{0.21}$$
$$R^2 = .98$$

Legend: ■ Observed, — Predicted

PHABSIM may be used to calculate total area, which, when divided by the total length, becomes the mean wetted width.

7.   Width's B Term (essentially dimensionless) — From the above discussion, you can see how to calculate the B term from the log-log plot. This plot may be in either English or international units. The B term is calculated by linear measurements from this plot. Leopold et al. (1964, p.244) report a variety of B values from around the world. A good default in the absence of anything better is 0.20; you may then calculate A if you know the width at a particular flow.

8. Manning's n or Travel Time (seconds/mile or seconds/kilometer) — Manning's n is an empirical measure of the segment's "roughness." A hydrologist can help you estimate or measure the stream roughness. A generally acceptable default value is 0.035. This parameter is necessary only if you are interested in predicting the minimum and maximum daily fluctuation in temperatures. It is not used in the prediction of the mean daily water temperature. Barnes (1967) may be useful in estimating Manning's n.

Values greater than 1.0 will be interpreted as Travel Time. Dye studies may yield accurate measures of travel time. (See Hubbard, 1982.)

TIME OF YEAR

The default screen for time of year looks like:

Time of Year
Month/day (mm/dd)   08/16

Month/Day (mm/dd) — Enter the number of the month and day to be modeled. January is month 1, etc. This program's output is for a single day. To compute an average value for a longer period (up to one month), simply use the middle day of that period. The error encountered in so doing will usually be minimal. **Note** that any month in SSTEMP can contain 31 days.

METEOROLOGICAL PARAMETERS

The default screen for meteorological parameters looks like:

```
┌─ Meteorology ──────────────────────┐
│                                    │
│   Air Temperature (°F)    │ 90.000 │
│                                    │
│ ☐ Maximum Air Temp (°F)   │ 94.201 │
│                                    │
│   Relative Humidity (%)   │ 60.000 │
│                                    │
│   Wind Speed (mph)        │  8.000 │
│                                    │
│   Ground Temperature (°F) │ 55.000 │
│                                    │
│   Thermal gradient (j/m²/s/c) │ 1.650 │
│                                    │
│   Possible Sun (%)        │ 90.000 │
│                                    │
│   Dust Coefficient        │  5.000 │
│                                    │
│   Ground Reflectivity (%) │ 25.000 │
│                                    │
│   Solar Radiation (Langleys/d) │ 565.410 │
└────────────────────────────────────┘
```

   1. Air Temperature (°F or °C) — Enter the mean daily air temperature. This information may of course be measured (in the shade), and should be for truly accurate results; however, this and the other (following) meteorological parameters may come from the Local Climatological Data (LCD) reports which can be obtained from the National Oceanic and Atmospheric Administration for a weather station near your site. The LCD Annual Summary contains monthly values, whereas the Monthly Summary contains daily values.

If only scoping-level analyses are required, you may refer to sources of general meteorology for the United States, such as USDA (1941) or USDC (1968).

Use the adiabatic lapse rate to correct for elevational differences from the met station:

$$Ta = To + Ct * (Z - Zo)$$

where Ta = air temperature at elevation E (°C)
        To = air temperature at elevation Eo (°C)
        Z = mean elevation of segment (m)
        Zo = elevation of station (m)
        Ct = moist-air adiabatic lapse rate (-0.00656 °C/m)

NOTE: Air temperature will usually be the single most important factor in determining water temperature. See Sensitivity Analysis for more on this subject.

  2. Maximum Air Temperature (°F or °C) – The maximum air temperature is a special case of an override condition. Unlike the other parameters where simply typing a value influences which parameters "take effect", the maximum daily air temperature overrides only if the check box is checked. If the box is not checked, the program continues to estimate the maximum daily air temperature from a set of empirical coefficients (see Theurer, et al., 1984) and will print the result in the grayed data entry box. You cannot enter a value in that box unless the box is checked. **Note:** maximum air temperature appears in the Intermediate Values portion of the screen, not with the other mean daily meteorology values.

  3. Relative Humidity (percent) ⎯ Obtain the mean daily relative humidity for your area by measurement or from the LCD by averaging the four daily values given in the report. Correct for elevational differences by:

$$Rh = Ro * [1.0640 \wedge (To-Ta)] * [(Ta+273.16)/(To+273.16)]$$

where Rh = relative humidity for temperature Ta (decimal)
        Ro = relative humidity at station (decimal)
        Ta = air temperature at segment (°C)
        To = air temperature at station (°C)
        $\wedge$ = exponentiation
        $0 <= Rh <= 1.0$

  4. Wind Speed (miles per hour or meters/second) ⎯ Obtainable from the LCD. Wind speed also may be useful in calibrating the program to known outflow temperatures by varying it within some reasonable range. In the best of all worlds, SSTEMP would like wind speed to be right above the water's surface.

  5. Ground Temperature (°F or °C) ⎯ Use mean annual air temperature from the LCD.

  6. Thermal Gradient (Joules/Meter^2/Second/°C) ⎯ This elusive quantity is a measure of rate of thermal input (or outgo) from the streambed to the water. It is not a particularly sensitive parameter within a narrow range. This parameter may prove useful in calibration, particularly for the maximum temperature of small, shallow streams where it may be expected that surface waters interact with either the streambed or subsurface flows. In the absence of anything better, simply use the 1.65 default. **Note** that this parameter is measured in the same units regardless of the system of measurement used.

  7. Possible Sun (percent) ⎯ This parameter is an indirect measure of cloud cover. Measure with a pyrometer or use the LCD.

  8. Dust Coefficient (dimensionless) ⎯ This value represents the amount of dust in the air. If you enter a value for the dust coefficient, SSTEMP will calculate the solar radiation.

Representative values look like the following (Tennessee Valley Authority, 1972):

        Winter - 6 to 13
        Spring - 5 to 13
        Summer- 3 to 10
        Fall   - 4 to 11

If all other parameters are known for a given event, the dust coefficient may be calibrated by using known ground-level solar radiation data.

9. Ground Reflectivity (percent) — The ground reflectivity is a measure of the amount of short-wave radiation reflected back from the earth into the atmosphere. If you enter a value for the ground reflectivity, SSTEMP will calculate the solar radiation.
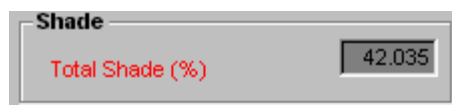
Representative values look like the following (Tennessee Valley Authority, 1972, and Gray, 1970):

Meadows and fields	14
Leaf and needle forest	5 to 20
Dark, extended mixed forest	4 to 5
Heath	10
Flat ground, grass covered	15 to 33
Flat ground, rock	12 to 15
Flat ground, tilled soil	15 to 30
Sand	10 to 20
Vegetation, early summer	19
Vegetation, late summer	29
Fresh snow	80 to 90
Old snow	60 to 80
Melting snow	40 to 60
Ice	40 to 50
Water	5 to 15

10. Solar Radiation (Langleys/day or Joules/meter^2/second) — Measure with a pyrometer, or refer to Cinquemani et al. (1978) for reported values of solar radiation. If you do not calculate solar radiation within SSTEMP, but instead rely on an external source of ground level radiation, you should assume that about 90% of the ground-level solar radiation actually enters the water. Thus, multiply the recorded solar measurements by 0.90 to get the number to be entered.   If you enter a value for solar radiation, SSTEMP will ignore the dust coefficient and ground reflectivity and "override' the internal calculation of solar radiation, graying out the unused input boxes. **Note**: this override is mandatory in the Southern Hemisphere.

SHADE PARAMETER

The default screen for the total shade value looks like:

Total Shade (percent) — This parameter refers to how much of the segment is shaded by vegetation, cliffs, etc. If 10% of the water surface is shaded through the day, enter 10. As a shortcut, you may think of the shade factor as being the percent of water surface shaded at noon on a sunny day. In actuality however, shade represents the percent of the incoming solar radiation that does not reach the water. If you enter a value for total shade, the optional shading parameters are ignored. You may find it to your advantage to use the Optional Shading Parameters to more accurately calculate stream shading.

OPTIONAL SHADING PARAMETERS

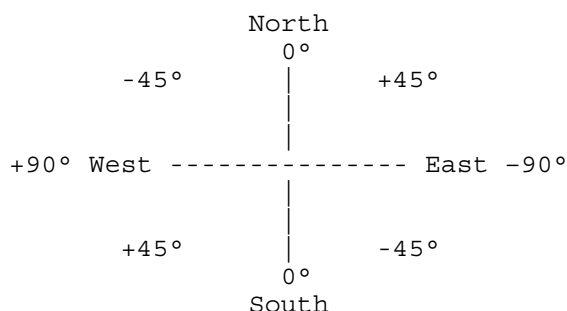The default screen for the optional shade values looks like:

There are many subjective factors in estimating shade. In general, I recommend not being too concerned with being accurate. Rather, estimate shade and then use your estimate plus or minus 25% as a calibration factor in SSTEMP.

There are, however, two conditions for which accuracy may matter more than others. The first would be if SSTEMP indicated that shade was a very sensitive parameter in water temperature (remember that it is more likely to be sensitive for the maximum daily temperature). The second is if the management prescription involves riparian vegetation management. Here, more accuracy is demanded. Taking multiple samples initially to calculate the number of samples for a satisfactory estimate of the mean and standard deviation may be required. See Platts et al. (1987) for a description of how sample size influences confidence intervals and how to calculate the required sample size to control your confidence in the estimates.

If any of the optional shade parameters are entered, SSTEMP will calculate the total shade, overriding any value you may have entered.

1. Azimuth (degrees or radians) — Azimuth refers to the general orientation of the stream segment with respect to due North and controls which sides are called East and West, by convention. Measure towards the west for positive degrees and towards the east for negative, regardless of the direction of flow. Refer to the following diagram for guidance:

```
                    North
                      0°
        -45°          |          +45°
                      |
                      |
  +90° West --------------- East -90°
                      |
                      |
        +45°          |          -45°
                      0°
                    South
```
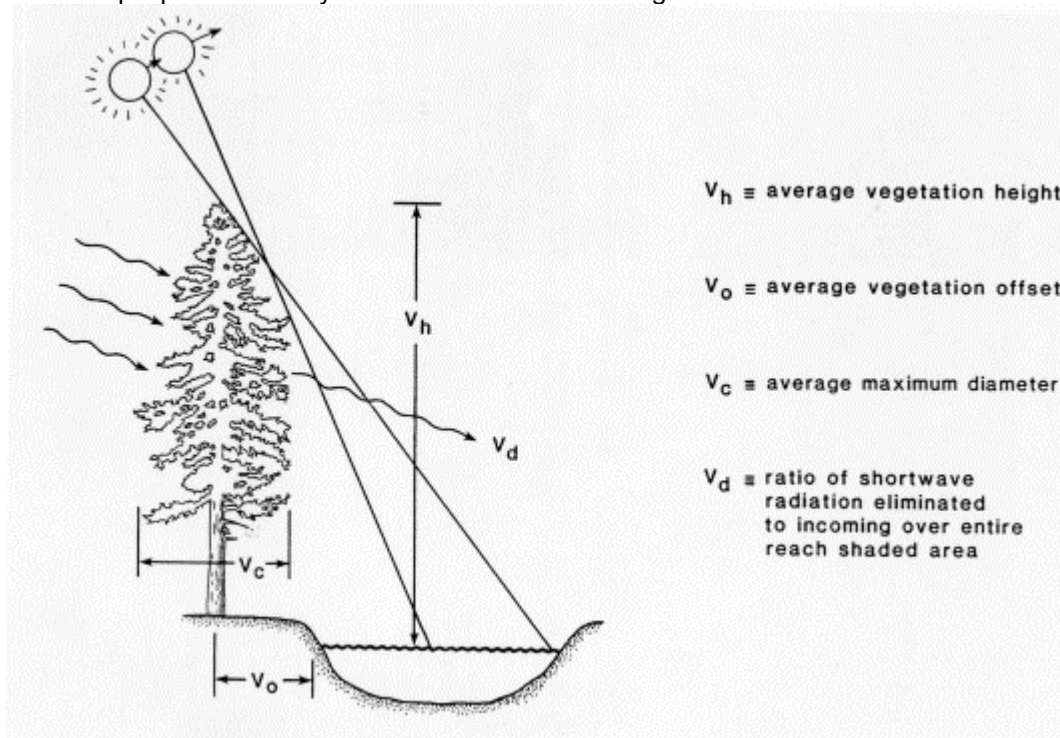
Once the azimuth is determined, usually from a topographic map, the East and West sides are fixed by convention. When the angle is small, East and West are obvious. As the angle approaches plus or minus 90 degrees, it is less clear. Imagine an azimuth of plus 90 degrees; the actual north shore is termed West. Similarly, if the azimuth is minus 90 degrees, the north shore is termed East as far as this program is concerned. This convention is easy to understand if you visualize varying the azimuth from zero degrees and noting that West and East always stay on the same side of the stream.

Since azimuth can be confusing to many people, the program prints a character (/, |, —, or \) along with labels for east and west to the right of the entry which designates the general orientation of that entry.

10

2. Topographic Altitude (degrees or radians) — This is a measure of the average incline to the horizon from the middle of the stream looking perpendicular to the direction of flow. Enter a value for both East and West Side. The altitude may be estimated from topographic maps but is best measured with a clinometer. In hilly country, the topographic maps may be used to estimate the incline; in mountainous terrain, it will be difficult to estimate topographic altitudes from a topo map; in flatter country, the stream bank itself may be the overriding horizon. Be careful!

3. Vegetation Height (feet or meters) — This is the average height of the shade producing strata of vegetation along the stream from the water's surface, Vh in the diagram below. Enter a value for both East and West sides.

The height may be calculated by the formula H = D * TAN (A), where H is the height, D the distance from the observer (in the water) to the vegetation, and A the angle from the water surface to the tops of the vegetation. A simple protractor may be used to estimate the angle.

$V_h \equiv$ average vegetation height

$V_o \equiv$ average vegetation offset

$V_c \equiv$ average maximum diameter

$V_d \equiv$ ratio of shortwave radiation eliminated to incoming over entire reach shaded area

Note: The question always arises as to how to handle the situation of trees on top of a high bank where the topographic horizon is defined by the bank and the trees are above, not below, the horizon. The easiest way to handle this as far as I'm concerned is to set the topographic altitude to zero and enter a height of vegetation as the total height above the water's surface. Then, include the bank in your estimate of vegetative density.

4. Vegetation Crown (feet or meters) — This is the average maximum crown diameter for the shade producing strata of vegetation along the stream, Vc in the diagram above. Enter a value for both East and West Side. Direct measurement or estimation from aerial photos may be used.

5. Vegetation Offset (feet or meters) — This is the average offset of the trunks of the shade producing strata of vegetation from the water's edge, Vo in the diagram above. You may need to vary this if the stream width varies substantially. Enter a value for both East and West sides.

6. Vegetation Density (percent) — This is the average screening factor (0 to 100%) of the shade producing strata of vegetation along the stream, Vd in the diagram above. It is composed of two parts: the continuity of the vegetative coverage along the stream (quantity), and the percent of light filtered by the vegetation's leaves and trunks (quality).

For example, if there is vegetation along 25% of the stream and the average density of that coverage is 50%, the total vegetative density is .25 times .50, which equals 0.125, or 12.5%. The value should always be between zero and one. Enter a value for both East and West Side.

To give examples of shade quality, an open pine stand provides about 65% light filtering; a closed pine stand provides about 75% light removal; a tight spruce/fir stand provides about 85% light removal; areas of extensive, dense emergent vegetation should be considered 90% efficient for the surface area covered. If you wish to be more precise, follow the procedure outlined below.

Purchase from a photographic supply store an item called an 18% gray card (about $5 US). Using an accurate, hand-held light meter, set the ASA value to a low number, such as 25. Set the f-stop to a high value, such as 16. Stand in direct sunlight and hold the light meter about six inches from the gray card such that the light meter only picks up light reflected from the gray card, being careful to cast no shadow yourself on the gray card. Read the exposure time from the meter; we will call the denominator of that exposure time Eo. Now repeat the measurement in the shade. This denominator we will call Ei. Then use the following formula to calculate the filtering effect:

> Shade quality = 1.0 - (Ei / Eo)

For example, if the in-shade exposure time is 1/50th of a second and the out-of-shade exposure time is 1/350th of a second, then

> Shade quality = 1.0 -(50 / 350)
>
> or

> Shade quality = 0.86

Note that this formulation requires that both values, Ei and Eo, be fractions, e.g., 1/350. If this is not so, readjust the f-stop such that both are fractions.

Shade continuity is best estimated from aerial photographs or by sampling along the stream bank. Density may need to be adjusted for the time of year if you are dealing with deciduous vegetation.

OUTPUT

The program will predict the minimum, mean, and maximum daily water temperature for the set of parameters you provide. The theoretical basis for the model is strongest for the mean daily temperature. The maximum is largely an estimate and likely to vary widely with the maximum daily air temperature. The minimum is computed by subtracting the difference between maximum and mean from the mean; but the minimum is always positive. The mean daily equilibrium temperature is that temperature towards which the daily mean water temperature will approach, but never reach, if all conditions remain the same (forever) as you go downstream. (Of course, all conditions cannot remain the same, e.g., the elevation changes immediately.) The maximum daily equilibrium temperature is that temperature towards which the daily maximum water temperature will approach. The result of the default values looks like:

Model Results - Outflow Temperature

Predicted Mean (°F) = 79.05

Estimated Maximum (°F) = 83.24

Approximate Minimum (°F) = 74.87

Mean Equilibrium (°F) = 84.23

Maximum Equilibrium (°F) = 89.47

Minimum Equilibrium (°F) = 78.99

Other output includes the intermediate parameters average width, average depth and slope, maximum daily air temperature (all calculated from the input parameters), and the mean daily heat flux components.

The intermediate values resulting from the default inputs look like:

Intermediate Values

Day Length (hrs) = 13.534

Slope (ft/100 ft) = 0.189

Width (ft) = 27.389

Depth (ft) = 1.005

Vegetative Shade (%) = 33.872

Topographic Shade (%) = 8.163

The mean heat flux components are abbreviated as follows:

    Convect. = convection component
    Conduct. = conduction component
    Evapor. = evaporation component
    Back Rad. = water's back radiation component
    Atmos. = atmospheric radiation component
    Friction = friction component
    Solar = solar radiation component
    Vegetat. = vegetative and topographic radiation component
    Net = sum of all the above flux values

The sign of these flux components indicates whether or not heat is entering (+) or exiting (-) the water. The units are in joules/meter^2/second. In essence, these flux components are the best indicator of the relative importance of the driving forces in heating and cooling the water from inflow to outflow. SSTEMP produces two sets of values, one based on the inflow to the segment and one based on the outflow. You may toggle from one to the other by double clicking on the frame containing the values. In doing so, you will find that the first four flux values change as a function of water temperature which varies along the segment. In contrast, the last four flux values do not change because they are not a function of water temperature but of constant air temperature and channel attributes. For a more complete discussion of heat flux, please refer to Theurer et al. (1984). The flux values resulting from the default inputs looks like:

```
┌ Mean Heat Fluxes at Inflow (j/m²/s) ──────────┐
│                                                │
│   Convect. = +98.39       Atmos. = +246.91     │
│                                                │
│   Conduct. = -13.75       Friction = +3.16     │
│                                                │
│   Evapor. = +67.78        Solar = +158.71      │
│                                                │
│   Back Rad. = -405.17     Vegetat. = +191.57   │
│              - - - - - - - - - - -             │
│                  Net = +347.58                 │
└────────────────────────────────────────────────┘
```

The program will predict the total segment shading for the set of parameters you provide. The program will also display how much of the total shade is a result of topography and how much is a result of vegetation. The topographic shade and vegetative shade are merely added to get the total shade. Use the knowledge that the two shade components are additive in solving perplexing questions related to vegetation standing atop a steep stream bank, or vegetation in the channel in front of a steep stream bank. In these conditions, if possible, only measure the vegetational shade that is more or less independent of the topographic shade.

SENSITIVITY ANALYSIS

```
Sensitivity for mean temperature values (10% variation)     SSTEMP (1.0.0)
Original mean temperature = 79.05°F
                              Temperature change (°F)
                                 if variable is:
Variable                       Increased Decreased   Relative Sensitivity
-----------------------------------------------------------------------------
Segment Inflow (cfs)               -0.02      +0.90 *****
Inflow Temperature (°F)            -2.50      +2.71 ***************
Segment Outflow (cfs)              +1.21      -0.43 ******
Accretion Temp. (°F)               -0.06      +0.06
Width's A Term (s/ft²)             -0.62      +0.67 ***
  B Term where W = A*Q**B          -0.51      +0.51 ***
Manning's n                        +0.00      +0.00
Air Temperature (°F)               -5.87      +4.92 *******************************
Relative Humidity (%)              -1.11      +1.12 ******
Wind Speed (mph)                   -0.08      +0.08
Ground Temperature (°F)            -0.13      +0.13 *
Thermal gradient (j/m²/s/c)        +0.05      -0.05
Possible Sun (%)                   -0.11      +0.16 *
Dust Coefficient                   +0.01      -0.01
Ground Reflectivity (%)            -0.02      +0.02
Segment Azimuth (degrees)          -0.01      +0.01
West Side:
Topographic Altitude (degrees)     +0.04      -0.04
Vegetation Height (ft)             +0.05      -0.05
Vegetative Crown (ft)              +0.03      -0.03
Vegetation Offset (ft)             -0.02      +0.02
Vegetation Density (%)             +0.10      -0.10 *
East Side:
Topographic Altitude (degrees)     +0.01       0.00
Vegetation Height (ft)             +0.06      -0.07
Vegetative Crown (ft)              +0.04      -0.04
Vegetation Offset (ft)             -0.06      +0.06
Vegetation Density (%)             +0.11      -0.11 *
```

SSTEMP may be used to compute a one-at-a-time sensitivity of your set of input values. Use
View|Sensitivity Analysis or the scale toolbar button to initiate the computation. This simply increases
and decreases most active input (i.e., non-grayed out values) by 10% and displays a screen for changes
to mean and maximum temperatures. The schematic graph that accompanies the display (see below)
gives an indication of which variables most strongly influence the results. This version does not compute
any interactions between input values.

FLOW/DISTANCE MATRIX

The **View|Flow/DistanceMatrix** option allows you to look at a variety of flow and distance combinations from your stream segment. You may enter up to five flows and five distances for further examination. The program will supply a default set of each, with flows ranging from 33% to 166% of that given on the main screen, and distances regularly spaced along the segment. After making any changes you may need, you may choose to view the results in simple graphs either as a function of distance (X) or discharge (Q). The units for discharge, distance and temperature used on the matrix and the graph are a function of those from the main form. The graph is discrete, i.e., does not attempt to smooth between points, and does not currently scale the X-axis realistically.

Note that changing the flow only changes the flow <u>through</u> the segment. That is, the accretion rate per unit distance will remain the same. Flow does impact shading (if active) and all other dependent calculations. For this reason, results may differ from the DOS version unless shading is fixed.

Note that you may enter distances beyond your segment length, but if you do so you are assuming that everything remains homogeneous farther downstream, just as you have assumed for the segment itself. *If you try to look at distances very close to the top of the segment, you may get mathematical instability.*

Note that the main form will vanish during matrix computations but it will be restored upon closing the matrix.

MAKING THE MOST OF SSTEMP OUTPUTS

SSTEMP is not fancy when it comes to output. But there are a variety of ways to get what you want.

Printing

There are essentially four options to print the results of SSTEMP.

1. Use the **Print Form** command available on the main menu and on command buttons on the sub-forms. **Print Form** is "quick and dirty" and you'll see what dirty means when you do it. If it takes forever on your printer, try reducing the resolution of your graphics image in **File|Print Setup|Properties**.

2. Press **Alt-Print Screen** to copy the active window to the Windows clipboard to paste into word processor or other application. Depending on the application, this may give much better results, not to mention your ability to control the scale, margins, and other features.

3. For the Sensitivity Analysis form only, you may select the text from the screen followed by the typical Windows **Cut, Copy,** and **Paste** commands. These commands are available by right-clicking the screen or by pressing **Shift-F10.** Note that SSTEMP uses a Courier New Bold font in the text window. This is not a proportional font and must not be proportional lest columns lose their correct spacing.

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4. You may use the contents of SSTEMP's data files as you please. These include:

a. **Save** file format. An example appears below. Note that one could generate a file to be read by SSTEMP using another application.

```
"SSTEMP (1.0.0)  ","04/21/1999  08:48 am"
"NoName"
"English",        "Segment Inflow (cfs)",        "50.000"
"English",        "Inflow Temperature (°F)",     "70.000"
"English",        "Segment Outflow (cfs)",       "51.000"
"English",        "Accretion Temp. (°F)",        "55.000"
"English",        "Latitude (degrees)",          "40.000"
"English",        "Segment Length (mi)",         "10.000"
"English",        "Upstream Elevation (ft)",     "100.000"
"English",        "Downstream Elevation (ft)",   "0.000"
"English",        "Width's A Term (s/ft²)",      "12.500"
"English",        "  B Term where W = A*Q**B",   "0.200"
"English",        "Manning's n",                 "0.035"
"English",        "Air Temperature (°F)",        "90.000"
"English",        "Relative Humidity (%)",       "60.000"
"English",        "Wind Speed (mph)",            "8.000"
"English",        "Ground Temperature (°F)",     "55.000"
"English",        "Thermal gradient (j/m²/s/c)", "1.650"
"English",        "Possible Sun (%)",            "90.000"
"English",        "Dust Coefficient",            "5.000"
"English",        "Ground Reflectivity (%)",     "25.000"
"English",        "Solar Radiation (Langleys/d)","565.410"
"English",        "Total Shade (%)",             "42.035"
"English",        "Segment Azimuth (degrees)",   "-15.000"
"West Side Parameters"
"English",        "Topographic Altitude (degrees)", "25.000"
"English",        "Vegetation Height (ft)",      "25.000"
"International",  "Vegetative Crown (m)",        "4.572"
"English",        "Vegetation Offset (ft)",      "5.000"
"English",        "Vegetation Density (%)",      "50.000"
"East Side Parameters"
"English",        "Segment Azimuth (degrees)",   "15.000"
"English",        "Topographic Altitude (degrees)", "35.000"
"English",        "Vegetation Height (ft)",      "6.096"
"International",  "Vegetative Crown (m)",        "15.000"
"English",        "Vegetation Offset (ft)",      "75.000"
"English",        " Maximum Air Temp (°F)",      "94.201"
"Dam at Head of Segment","Unchecked"
" Maximum Air Temp (°F)","Unchecked"
"Solar Radiation","Disabled"
"Total Shade","Disabled"
"Month/day","08/16"
        "Predicted Mean (°F) = 79.05"
        "Estimated Maximum (°F) = 83.24"
        "Approximate Minimum (°F) = 74.87"
        "Mean Equilibrium (°F) = 84.23"
        "Maximum Equilibrium (°F) = 89.47"
        "Minimum Equilibrium (°F) = 78.99"
```

b. **MEAN.SEN** and **MAX.SEN**. These "temporary" files are created every time you run a sensitivity analysis and may be used in any way you wish. They are identical to what appears in the SSTEMP text window.

DIFFERENCES FROM PREVIOUS VERSIONS OF SSTEMP

There are several differences in this version of SSTEMP:

Overall
   1. You may now choose the units of display (English or International) for each input and output item, not just "globally". Units are red if English and blue if International. **Note** that not all input or output values have units that differ between systems. Some may be expanded in future releases.

   2. As a 32-bit Windows application, SSTEMP is now more accurate and precise in its calculations. As such, you are not guaranteed the same answers as SSTEMP for DOS with essentially equivalent input data, but they will be close. The greatest differences are likely to be under extreme conditions such as near the Arctic Circle during the winter. (However, see **Known Deficiencies** item c below.)

   3. Obviously, Windows is the required operating system – 9x and NT. The best screen resolution is 1024 by 768.

SSSOLAR (V 1.6)
   1. Being integrated into SSTEMP has made it necessary to choose whether the program calculates its own radiation penetrating the water, or whether you *override* that calculation with your own estimate of Solar Radiation. By *default*, or if you actively enter either the Dust Coefficient or Ground Reflectivity, SSTEMP calculates the solar radiation penetrating the water and displays the result in the Solar Radiation input box, graying it out to show that that value has been overridden. Conversely, if you actively enter Solar Radiation, the Dust Coefficient and Ground Reflectivity are not needed and are grayed out to show that they have been overridden.

   2. Only a single day is simulated, i.e., there is no longer a beginning and ending month and day, nor is there a "# of days" integration value.

   3. The elevation used in calculating Solar Radiation is the mean for the segment.

   4. Latitude is no longer entered in degrees and minutes, only as decimal degrees.

   5. Extraterrestrial and ground level radiation are no longer printed out -- just not enough room.

SSSHADE (V 1.4)
   1. Being integrated into SSTEMP has made it necessary to choose whether the program calculates its own shading, or whether you *override* that calculation with your own estimate of Total Shade. By *default*, or if you actively enter any of the values in the Optional Shading Parameters frame, SSTEMP calculates the topographic and vegetative shade and displays the result in the Total Shade input box, graying it out to show that that value has been overridden. The *intermediate values* of topographic and vegetative shade also appear in the Intermediate Values frame. Conversely, if you actively enter Total Shade, the Optional Shading Parameters values are not needed and are grayed out to show that they have been overridden.

   2. Previously, there was a "disconnect" between the stream Width in SSSHADE and SSTEMP. In SSSHADE, the stream width was not a function of flow whereas width was a function of flow in SSTEMP (if you used the width's B term). This made the shade calculation potentially inaccurate if you left shading alone. Now, with the integrated models, width changes as a function of flow in the shade calculations, BUT the offset of the vegetation does not change realistically. Win some, lose some. Perhaps someday Offset will be to the center of the channel instead of to the water's edge and these difficulties will be eliminated.

SSTEMP (V 3.9)
   1. It's all new.

2. The ability to override the program's estimation of the maximum daily air temperature is both a change in SSTEMP and a difference from SNTEMP.
  3. SSTEMP can compute the relative sensitivity for the set of input values
  4. You can now plot the values in the flow/distance **Error! Bookmark not defined.**.

Version History

Version 1.1.3 8/98   Hid the estimates of vegetative and topographic shade if using total shade, and vice versa. Affected change routine and read file routine

Version 1.1.2 7/98   Changed hardwired 15 to twips per pixle x & y in Main

Version 1.1.1 5/98 - made main form sizable so it will show in task bar, but eliminated resize and max buttons

Version 1.1.0 5/98 - added better printform capability

Version 1.0.0 First Release, 4/98

KNOWN DEFICIENCIES

The program does not check for every possible combination of parameters that may cause mathematical "blowup" in the formulae. For example, if you accidentally input a downstream elevation that is higher than the upstream elevation, the program will print an error message, and then continue. You can be assured that the last change you made caused the problem. Similarly, there is a program bug that can occur if the latitude given is zero, i.e. on the equator.

In addition, some specific problems are known to exist:

  a. Manning's n/travel time values between 1.0 and 1.609344 are "unstable" and provide unreliable results. This should be no real problem because true travel times will be far in excess of 1.61, regardless of the system of units. It is unlikely that this is a problem with SNTEMP also.

  b. In some cases for which the inflow water temperature far exceeds the air temperature, the model is unstable and can generate maximum outflow temperatures that are less than the minimum temperatures. This may be a problem with SNTEMP also.

  c. There can a loss of precision throughout SSTEMP in terms of how data are entered and how they are converted between systems of units. Repeatedly swapping units, either globally or individually, may produce slight differences in output, occasionally manifesting itself as a "drift" at about the hundredth of a degree level. If this is a problem for you, I suggest that you work only in metric units and adapt a convention of always using three decimal places.

  d. The Windows version cannot read previous versions of SSTEMP output files as input for this version.

  e. Note that there is a problem maintaining the units for intermediate and final answers upon reading an external data set. Solution is to print the units to the file and restore them. Workaround is to set units to what you want prior to read, or to double click on each item to change it.

ASSUMPTIONS

  a. Water in the system is instantaneously and thoroughly mixed at all times. Thus there is no lateral temperature distribution across the stream channel, nor is there any vertical gradient in pools.

b. All stream geometry (e.g., slope, shade, friction coefficient) is characterized by mean conditions. This applies to the full travel distance upstream to solar noon, unless there is a dam at the upstream end.

c. Distribution of lateral inflow is uniformly apportioned throughout the segment length.

d. Solar radiation and the other meteorological and hydrological parameters are 24-hour means. You may lean away from them for an extreme case analysis, but you risk violating some of the principles involved. For example, you may alter the relative humidity to be more representative of the early morning hours. If you do, the mean water temperature may better approximate the early morning temperature, but the maximum and minimum temperatures would be meaningless.

e. Each parameter has certain built-in upper and lower bounds to prevent outlandish input errors. These limits are not unreasonable; however, the user should look to see that what he or she types actually shows up on the screen. The screen image will always contain the values that the program is using.

f. This model does not allow either Manning's n or travel time to vary as a function of flow.

g. The program should be considered valid only for the Northern Hemisphere below the Arctic Circle. One could theoretically "fast forward" six months for the Southern Hemisphere's shade calculations, but this has not been tested. The solar radiation calculations would, however, be invalid due to the asymmetrical elliptical nature of the earth's orbit around the sun.

h. The representative time period must be long enough for water to flow the full length of the segment. This is always a difficult one to explain, so bear with me. Remember that SSTEMP, like SNTEMP, is a model that simulates the mean (and maximum) water temperature for some period of days. (One day is the minimum time period, and theoretically, there is no maximum, although a month is likely the upper pragmatic limit.) SSTEMP looks at the world as if all the inputs represent an average day for the time period. For this reason, SSTEMP also assumes that a parcel of water entering the top of the study segment will have the opportunity to be exposed to a full day's worth of heat flux by the time it exits the downstream end. If this is not true, the time period must be lengthened.

Let's make this more concrete. Suppose your stream has an average velocity of 0.5 meters per second and you want to simulate a 10 km segment. With 86,400 seconds in a day, that water would travel 43 km in a day's time. As this far exceeds your 10 km segment length, you can simulate a single day if you wish. But if your stream's velocity were only 0.05 mps, the water would only travel 4.3 km, so the averaging period for your simulation must be at least 3 days to allow that water to be fully influenced by the average conditions over that period. If, however, most conditions (flow, meteorology) are really relatively stable over the 3 days, you can get by with simulating a single day. Just be aware of the theoretical limitation.

i. Remember that SSTEMP does not and can not deal with cumulative effects. For example, suppose you are gaming with the riparian vegetation shade's effect on stream temperature. Mathematically adding or deleting vegetation is not the same as doing so in real life, where such vegetation may have subtle or not so subtle effects on channel width or length, air temperature, relative humidity, wind speed, and so on.

WARNING OR ERROR MESSAGES

SSTEMP is mathematically unstable above latitudes for which the sun never rises for a given time of year. Other special cases may cause mathematical errors also, such as having the stream flow uphill. Any program error will cause a message followed by reversion to the user-input. The user may reasonably assume that the last value typed is the one that caused the error. Correct the errant value and try again.

COMPUTING REQUIREMENTS

Windows is the required operating system – 9x or NT. The recommended screen resolution is 1024 by 768. Installation may consume up to 6 megabytes after temporary files are removed.

SSTEMP can utilize a printer for screen image printing, however a printer is not required.

PROGRAM DISTRIBUTION

SSTEMP is in the public domain and may be copied and distributed freely. We ask only three things of those who use the program:

1. Please report any errors or questions to the USGS at the address listed below.

2. Please let us know about your applications of SSTEMP. We need to be kept aware to improve our understanding of your needs.

3. When distributing copies of this program, make sure that all relevant program files and documentation are included.

FOR MORE INFORMATION

USGS strongly encourages users of the stream segment and stream network temperature models to take the IF 312 course, offered in a correspondence format. Please see the following sources for additional information, and visit our web site at http://www.mesc.usgs.gov/rsm.

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QUESTIONS, SUGGESTIONS, ERROR REPORTS

Please direct questions or suggestions to:

Acknowledgements

In no way do I pretend that I have solved all the problems or made SSTEMP a glowing example of professional software. But I have, I believe, made improvements from the DOS version and remain supportive of the software as a learning tool on the path to SNTEMP, which is, after all, its original purpose.